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(54) Title: A METHOD FOR THE PRODUCTION OF HIGHLY PURE METALLIC NANO-POWDERS AND NANO-POWDERS PRODUCED THEREBY

(57) Abstract: The present invention discloses a novel method for the production of metallic nano-powder. This cost-effective, simple process is customized for a full-scale production of metallic nano-powders containing a first metal, and comprising the following of forming an alloy comprising said first metal and at least one soluble metal; applying first thermal treatment in the manner homogenized alloy is obtained; applying a cold work to the homogenized alloy so thin strips are obtained; applying a second thermal treatment to the alloy until a phase composition of predetermined characteristics is obtained; subjecting the said alloy to a leaching agent adapted to effectively leach out the least one soluble metal; filtering and washing the powder; washing the powder; drying the powder; coating the powder with chemicals; and then de-agglomerating the coated powder. The present invention also discloses a cost-effective and highly pure metallic powder produced by the method defined above.

10/518227

# A METHOD FOR THE PRODUCTION OF HIGHLY PURE METALLIC NANO-POWDERS AND NANO-POWDERS PRODUCED THEREBY

## FIELD OF THE INVENTION

The present invention generally relates to a method for the production of highly pure metallic nano-powders and to powders produced thereof. More specifically, the present invention relates to metallic silver, metal elements, copper, platinum, nickel, palladium, titanium, gold, cobalt and blends comprising such metals (alloys) nano-powders wherein the particle size is in the range of 1 to 100 nm.

## BACKGROUND OF THE INVENTION

Nano-powders are single or multi-phase polycrystals comprises particles with sizes of 1 to 100 nm in at least one direction. Various methods were suggested in the literature for the production of well-defined nano-powders. Some of them, such as presented in U.S. Pat. No. 6,312,643 to Upadhya et al. are respectively tedious and costly operation, comprises no less than 21 steps, treating the material in all solid, liquid and gas phases; wherein gas is evacuated from one processing chamber to less than  $10^{-3}$  Torr, and then pressed in another processing chamber to at least  $10^3$  psi, heated to some 550°C etc.

U.S. Pat. No. 6,054,495 to Markowitz et al. presents a powder of un-agglomerated metallic particles, made by making at least four dispersions of surfactants vesicles in the presence of metal ions, and then freeze-drying the obtained lipid phase. This costly method requires the operator to continuously control this very delicate, inflammable, multi-phase and complicated system, decreasing its compatibility with full-scale operations.

U.S. Pat. 5,476,535 to the applicant present a method for the production of nano-powders, especially of silver. This process comprising the steps of (a) forming an aluminum-silver alloy of a specific blend composition; (b) leaching the aluminum ingredient by a series of consequent leaching steps wherein a fresh leaching agent is reacting the treated solid material, providing a gradually porous and homogeneous silver alloy. Ultrasonic oscillations are applied in step (c), disintegrating the agglomerate and enhancing the penetration of the

leaching agent into the ever growing porous of the alloy by the application of a plurality of ultrasonic oscillations. The leaching agent is leaving silver agglomerate in step (d), and then the agglomerate is washed and dried in a final step.

According to U.S. Pat. No. 6,012,658 to the applicant, the very same process was used as is to form metal flasks. Thus, the following two main steps were introduced: comminuting the alloys obtained by the aforementioned U.S. Pat. No. 5,476,535 into defined particles, and then filtering the obtained particles into strip-like highly porous alloys of predetermined characteristics.

Thus, there exists a need for cost-effective, simple process customizable for full-scale production of metallic nano-powders and to the valuable products produced thereof.

#### SUMMARY OF THE INVENTION

It thus the object of the present invention to provide a useful and novel method for the production of metallic nano-powders, comprising the steps: (a) forming an alloy comprising a first metal or metal, preferably silver, copper, platinum, palladium, titanium, nickel, gold, cobalt and blends comprising such metals (alloys), yet not limited to said metals, and at least one another second soluble metal or metals, preferably, yet not limited to aluminum, magnesium, zinc or tin. (b) applying first thermal treatment in the manner homogenized alloy is obtained; (c) applying a cold work to the homogenized alloy so thin strips are obtained; (d) applying a second thermal treatment to the said alloy until a phase composition of predetermined characteristics is obtained; (e) subjecting the said alloy to a leaching agent adapted to effectively leach out the least one soluble metal; (f) filtering and washing the powder; (g) drying the powder; (h) coating the powder with chemicals; and lastly, (i) de-agglomerating the coated powder.

This method is based on gradually single leaching step and plurality of few thermal treatings, avoid using ultrasonic processes, and comprising a novel technique of coating the powder with predetermined chemicals which provides the obtained powder better de-agglomeration properties and de-agglomeration process.

It is another object of the present invention to provide pure metallic powder having particle size of nano scale, produced in the method defined above. More specifically, the aim of the present invention is to introduce a nano-powder comprising about 99.0% - 99.6% desired metal and less than 1% soluble metal, having a specific area of about 6 to 25 m<sup>2</sup> per gram and characterized by an average particle size of about 50 to 100 nm.

#### DETAILED DESCRIPTION OF THE INVENTION

It is thus in the scope of the present invention to present a useful method for the production of metallic nano-powder of a first metal. Said method is essentially comprising the following at least nine steps:

- i. forming an alloy comprising a first metal and at least one another second soluble metal;
- ii. applying first thermal treatment in the manner homogenized alloy is obtained;
- iii. applying a cold work to the homogenized alloy so thin strips are obtained;
- iv. applying a second thermal treatment to the said alloy until a phase composition of predetermined characteristics is obtained;
- v. subjecting the said alloy to a leaching agent adapted to effectively leach out the least one soluble metal;
- vi. filtering and washing the powder;
- vii. drying the powder;
- viii. coating the powder with chemicals; and lastly,
- ix. de-agglomerating the coated powder.

It is acknowledged that while the present invention has been described with the respect to a plurality of few preferred examples, it will be appropriated that many variations, modifications and applications of the invention may be made.

It is hence in the general scope of the present invention, wherein the first metal is selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements. More specifically, said first metal is selected from, copper, nickel, cobalt, titanium, silver, palladium, platinum, gold and iridium. Most particularly, silver is said first metal. In addition, various alloys comprising a blend of the said silver and at least one other metal,

selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements. More specifically, cooper, aluminum, nickel, cobalt, titanium, palladium, platinum, gold, iridium or - any mixture thereof is suitable to be comprised in the aforementioned alloy.

In addition, it is also in the scope of the invention, wherein the at least one soluble metal is selected from aluminum, zinc, magnesium, tin, copper and silver. In one embodiment of the present invention is wherein the concentration of the at least one soluble metal is near saturation. Most specifically, the present invention relates thus to a method to produce a nano-powder, wherein silver is the first metal and aluminum is the soluble metal.

It is acknowledged that the preferred concentration of the soluble metal ingredient of the said processed alloy is in the range between 5 to 90 % w/w.

As said above, the method according to the present invention comprises at least one step of leaching. Suitable leaching agents are preferably selected from sodium hydroxide, potassium hydroxide, acetic acid, hydrochloric acid, formic acid, sulfuric acid, hydrofluoric acid, nitric acid or any combination thereof. It is acknowledged that a sequent of few leaching steps useful to extract the soluble metal from the alloy, wherein in each leaching step comprising different leaching agent at possibly different concentration.

The hereto-defined method may additionally comprise at least one step of surface cleansing wherein the obtained strips are treated by means of at least one cleaning agent. Those cleansing agents are preferably selected from nitric acid, potassium hydroxide, sodium hydroxide or a mixture thereof.

According to the present invention, the term 'heat treatment' is defined as any heating, cooling, smelting, fusing or melting, amalgamating, liquidating, sustaining a substrate in a predetermined temperature and for a predetermined period or any combination thereof. It is thus in the scope of the present invention, wherein the temperature ranges of first thermal treatment is about 400°C for 2 to 4 hours, or alternatively, until a homogenized alloy is obtained. Similarly, According to the present invention, the term 'cold work' is defined as any work or force provided on the substrate. This work is selected, yet not limited to pressing, compressing, squashing, mashing, pulverizing, grinding, milling or any

combination thereof. Thus, the aforementioned method comprises a step of cold work as defined above, useful for applying the obtained strip a thickness in the range of 0.3 to 1.0 mm or thinner.

In one specific embodiment of the present invention, especially adapted to the family of silver-aluminum alloys, the above mentioned second thermal treatment is adapted to the range of 460°C to 610°C. Said method according to the present invention may additionally comprising a step of quenching steps, wherein the strips obtained from the oven are to be treated by means of immersing them in cold water, so the predetermined phase composition obtained during the heat treatment is provided.

According to the present invention, sodium hydroxide is a useful leaching agent, adapted to be effective wherein the leaching temperature is between 36°C to 80°C.

In one specific embodiment of the present invention, silver is the first metal and aluminum is the soluble metal. Here, the concentration of the aforementioned sodium hydroxide is between 25 to 55 % (w/w) and the molar ratio of the aluminum to the said sodium hydroxide is between 5 to 6.

The obtained powder is preferably to be filtered and washed by water so pH in the range of 6 to 7 is provided and further wherein at a maximum temperature of 45°C, the powder to a LOD weight ratio is lower 1%.

The present invention relates to various chemical compositions, some of them are widely known in the art in their trademark name. Those terms are denoted in the present invention according their definitions introduced in Table 1 below:

Trade name	Chemical name
Arlacel 60	sorbitan sesquioleate
Arlacel 83	sorbitan sesquioleate
Brig 30	polyoxyethylene lauryl ester
Brij 35	Polyoxyethylene lauryl ester
Cetyl alcohol	Hexadecanol
Diethylene glycol	monolaurate
Glyceryl monostearate	glyceryl monostearate
Lauroglycol	propylene glycol monostearate
Methocel	Methylcellulose
Myrj 45	Polyoxyethylene monostearate
Myrj 49	Polyoxyethylene monostearate
Myrj 52	polyoxyl 40 stearate
PEG 400	polyoxyethylene monolaurate
PEG 400 monoleate	polyoxyethylene monooleate
PEG 400 monostearate	polyoxyethylene monostearate
Pluronic F-68	gelatin
Potassium oleate	poloxamer
Span 20	Sorbitan monolaurate
Span 40	sorbitan monopalmitate
Span 60	sorbitan monostearate
Span 65	sorbitan tristearate
Span 80	Sorbitan mono-oleate
Span 85	Sorbitan trioleate
Tween 20	Polyoxyethylene sorbitan monolaurate
Tween 21	polyoxyethylene sorbitan monolaurate
Tween 40	polyoxyethylene sorbitan monopalmitate
Tween 60	polyoxyethylene sorbitan monostearate
Tween 61	polyoxyethylene sorbitan monostearate
Tween 65	Polyoxyethylene sorbitan tristearate
Tween 80	Polyoxyethylene sorbitan mono-oleate
Tween 81	polyoxyethylene sorbitan monooleate
Tween 85	Polyoxyethylene sorbitan trioleate
sorbic acid	2,4 hexadienoic acid
TOPO	trioctylphosphine oxide
TOP	trioctylphosphine
T1124	Ammonium salt of poly carboxylic acid

Table 1. The trade name and the chemical name of chemicals utilized in the present invention.

It was stressed above that various chemicals are useful for coating the powder. According to the present invention, chemicals hereby defined, yet not limited to this list, are selected from sorbitan esters, polyoxyethylene esters, alcohols, glycerin, polyglycols, organic acids salts and esters, thiols, phosphines, acrylics and polyesters or any other suitable low molecular weight polymers or combination thereof were found to comprise superior effectively.

Moreover, it is hereby acknowledged that chemicals for coating the powder are admixed to the range of 1 to 5%, weight-by-weight based on the metal. Alternatively, least two different chemicals are to be used for coating the powder. In this case, at least one primary chemical is admixed in the range 1% to 5%, and at least one secondary chemical is admixed in the range of 0.1 to 2.5% weight by weight based on the metal. Table 2 presents an extracted list of useful combinations of both primary and secondary chemicals.

<b>Primary Chemical</b>	<b>Secondary Chemical</b>
Tween 80	Oleic Acid
Span 20	Tween 20
Span 60	Hexadecanol
Span 65	Tween 20
Span 80	Hexadecanol
Span 80	cetyl alcohol
Span 20	Oleic Acid
Span 20	Octanol
Span 60	Glycerin
Span 60	Propylene Glycol
Span 65	Tween 20
Span 20	Hexadecanol
Glycerin Mono	Glycerine
Span 60	Glycerine
poloxyethylene (23)	Span 60
poloxyethylene (4)	Span 60
Palmitic Acid	Glycerin

Table 2: Various combinations of both primary and secondary chemicals useful for coating the powder:

It also in the scope of the present invention wherein the method for the production of the said metallic nano-powers additionally comprises the following steps:

- a. dissolving the chemicals in a solvent;
- b. admixing the dissolved chemicals with the metal powder by an efficient mean; and then,
- c. drying the slurry in an oven at low temperature.

The above-mentioned solvent is preferably selected from of low boiling temperature solvent, and more specifically from methanol, ethanol, isopropanol, acetone, water or combination



thereof. It is also suggested according to use a ball mill to admixed the dissolved chemicals with the metal powder.

It is also in the scope of the present invention, wherein the said de-agglomeration of the said coated powder is enabled by means of a dry process, using at least one jet mill. Additionally or alternatively, said de-agglomerating of the coated powder is also enabled by means of a wet process, using effective means selected from of any suitable mechanical dispersers, mechanical homogenizers, ultra sonic homogenizers or any combination thereof. In this respect, means selected from, yet not limited to rotor/stator; rotors; dispersing elements; mechanical homogenizers; ultra-sonic homogenizers; ball milling and/or any other suitable de-agglomeration means are acknowledged as useful.

It is well in the scope of the present invention to provide a metallic nano-powder produced by the method as defined above. In general, said metal is selected from the group I, IV, V, VI, VII and VIII of the periodic table of elements. More specifically, the said metal powder is selected from silver, cooper, nickel, cobalt, titanium, silver, palladium, platinum, gold and iridium. In addition, said produced nano-powder comprises metal that is preferably selected from alloys comprising a blend of silver and at least one other metal, selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements.

## EXPERIMENTAL

A metallic nano-powder comprising silver, silver-cooper, silver palladium, silver-platinum, and cooper was produced by the method of forming an alloy comprising said first metal and at least one soluble metal, selected from aluminum, zinc and magnesium, applying first thermal treatment in the manner homogenized alloy is obtained; applying a cold work to the homogenized alloy so thin strips are obtained; applying a second thermal treatment to the previously leached alloy until a phase composition of predetermined characteristics is obtained; subjecting the said alloy to a leaching agent (i.e., sodium hydroxide, hydrochloride, formic acid and sulfuric acid) adapted to effectively leach out the least one soluble metal; filtering and washing the powder; drying the powder; coating the powder with chemicals; and then, de-agglomerating the coated powder by various means (e.g., using the commercial available Kinematica or jet mills):

Exp. No.	Powder			Auxiliary		First Leaching			
	Metal Alloy	Main metal Quantity	Second metal Quantity	Metal	Quantity	Leaching Chemical	Chemical Quantity	Water Quantity	Solution Volume
1	Ag	3,000	0	Al	7,000	NaOH	48 KG	144 L	150 L
2	Ag/Cu	2,925	75	Al	12,000	NaOH	48 KG	144 L	150 L
3	Ag/Cu	2,925	75	Al	12,000	NaOH	48 KG	144 L	150 L
4	Ag/Pd	2,940	60	Al	12,000	NaOH	48 KG	144 L	150 L
5	Ag/Pt	2,940	60	Al	12,000	NaOH	48 KG	144 L	150 L
6	Cu	620	0	Al	2,560	NaOH	34 KG	100 L	104 L
7	Cu	50	0	Zn	150	HCl	2 Kg HCl 32%	2 L	4 L
8	Cu	50	0	Mg	150	Formic acid	2.8 Kg F.A. 85%	3.2L	6 L
9	Cu	100	0	Mg	150	H2SO4	1.2 Kg H2SO4	4.8 L	6 Kg

  

Exp. No.	Second Leaching				Powder Quantity after leaching	Deagglomeration Process	
	Leaching Chemical	Chemical Quantity	Water Quantity	Solution Volume		Chemicals (coating)	Technique
1	NaOH	1.6 KG	3.4 L	6.4 L	2880	see table 4	JM
2	NaOH	1.6 KG	3.4 L	6.4 L	2880	see table 4	JM
3	NaOH	1.6 KG	3.4 L	6.4 L	2880	see table 4	Kinematica
4	NaOH	1.6 KG	3.4 L	6.4 L	2880	see table 4	JM
5	NaOH	1.6 KG	3.4 L	6.4 L	2880	see table 4	JM
6	HCl	3 Kg HCl 32%	3.0 L	6.0 L	610	see table 4	JM
7	HCl	0.5 Kg HCl 32%	0.5 L	1 L	49	see table 4	JM
8	HCl	0.5 Kg HCl 32%	0.5 L	1 L	49	see table 4	JM
9	HCl	1 Kg HCl 32%	1 L	2 L	98	see table 4	Kinematica

Table 3: Nine different experiments of producing metallic nano-powders by means of the present invention.

Experiment	Metal Alloy	De-agglomeration Process		Total Powder yield, %
		Chemicals (coating)	Technique	
		Quantities per 1 kg powder		
1	Ag	156 g Span 80; 144 g Cetyl Alcohol	JM	85
2	Ag/Cu	120 g Span 20; 180 g Oleic acid	JM	85
3	Ag/Cu	300 g Tween 80	Kinematica	90
4	Ag/Pd	300 g Span 60	JM	85
5	Ag/Pt	150 g Palmitic acid; 150 g Glycerine	JM	85
6	Cu	300 g Byk 140	JM	90
7	Cu	200 g Span 20; 100 g cetyl alcohol	JM	90
8	Cu	300 g Trioctylphosphine Oxide	JM	90
9	Cu	300 g Octanethiol	Kinematica	92

Table 4: Nine different coating systems to produce nano-metal particles according to this invention.

## CLAIMS

1. A method for the production of metallic nano-powder of a first metal or metals comprising;
  - i. forming an alloy comprising said first metal or metals and at least one another second soluble metal;
  - ii. applying first thermal treatment in the manner homogenized alloy is obtained;
  - iii. applying a cold work to the homogenized alloy so thin strips are obtained;
  - iv. applying a second thermal treatment to the alloy until a phase composition of predetermined characteristics is obtained;
  - v. subjecting the said alloy to a leaching agent adapted to effectively leach out the least one soluble metal;
  - vi. filtering and washing the powder;
  - vii. drying the powder;
  - viii. coating the powder with chemicals; and,
  - ix. de-agglomerating the coated powder.
2. The method according to claim 1, wherein the first metal is selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements.
3. The method according to claim 2, wherein the first metal is selected from silver, copper, nickel, cobalt, titanium, silver, palladium, platinum, gold and iridium.
4. The method according to claim 1, wherein the first metal is selected from alloys comprising a blend of silver and at least one other metal, selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements.
5. The method according to claim 4, wherein at least one soluble metal blended in the silver alloy is selected from silver and at least one of the following metals: copper, aluminum, nickel, cobalt, titanium, silver, palladium, platinum, gold and iridium.
6. The method according to claim 1, wherein the at least one soluble metal is selected from aluminum, zinc, magnesium, tin, copper and silver.

7. The method according to claim 1, wherein the concentration of the at least one soluble metal is near saturation.
8. The method according to claim 1, wherein silver is the first metal and aluminum is the soluble metal.
9. The method according to claim 8, wherein the concentration of the soluble metal ingredient of the alloy is in the range between 5 to 50% w/w.
10. The method according to claim 1, wherein the leaching agent is selected from sodium hydroxide, potassium hydroxide, Acetic acid, hydrochloric acid, formic acid, sulfuric acid, nitric acid and hydrofluoric acid.
11. The method according to claim 1, additionally comprising a step of surface cleansing of the obtained strips by at least one cleaning agent.
12. The method according to claim 11, wherein the cleansing agent is selected from nitric acid, potassium hydroxide, sodium hydroxide or a mixture thereof.
13. The method according to claim 1, wherein the temperature ranges of first thermal treatment is about 400°C for 2 to 4 hours, or until homogenized alloy is obtained.
14. The method according to claim 1, wherein the cold work is applied on the strip until the thickness of said strip is between 0.3 to 1.0 mm.
15. The method according to claim 1 adapted to silver-aluminum alloys, wherein the second thermal treatment is between 460 to 610°C.
16. The method according to claim 1, additionally comprising a step of quenching the strips obtained from the oven by means of immersing them in cold water, so the predetermined phase composition obtained during the heat treatment is provided.

17. The method according to claim 12, wherein sodium hydroxide is the leaching agent and the leaching temperature is between 36 to 80°C.
18. The method according to claim 17 wherein silver is the first metal and aluminum is the soluble metal and further wherein the concentration of the sodium hydroxide is between 25 to 55% (w/w) and the molar ratio of the aluminum to the said sodium hydroxide is between 5 to 6.
19. The method according to claim 1, wherein the obtained powder is filtered and washed by water so pH in the range of 6 to 7 is obtained.
20. The method according to claim 1, wherein at a maximum temperature of 45°C, the powder to a LOD weight ratio is lower 1%.
21. The method according to claim 1, wherein the chemicals for coating the powder are selected from sorbitan esters, polyoxyethylene esters, alcohols, glycerin, polyglycols, organic acids salts and esters, thiols, phosphines, acrylics and polyesters or any other suitable low molecular weight polymers or combination thereof.
22. The method according to claim 1, wherein the chemicals for coating the powder are admixed to the range of 1 to 5%, weight by weight based on the metal.
23. The method according to claim 1, wherein at least two different chemicals are used for coating the powder, at least one primary chemical is admixed in the range 1% to 5%, and at least one secondary chemical is admixed in the range of 0.1 to 2.5% weight by weight based on the metal.
24. The method according to claim 1, wherein the coating comprising;
  - i. dissolving the chemicals in a solvent;
  - ii. admixing the dissolved chemicals with the metal powder by an efficient mean;
  - iii. drying the slurry in an oven at low temperature.
25. The method according to claim 24, adapted to use a solvent of low boiling temperature.

26. The method according to claim 25, wherein the low boiling temperature solvent is selected from methanol, ethanol, isopropanol, acetone, water or combination thereof.
27. The method according to claim 24, adapted to use a ball mill is the efficient mean to admixed the dissolved chemicals with the metal powder.
28. The method according to claim 1, wherein the de-agglomerating the coated powder is enabled by means of a dry process, using at least one jet mill.
29. The method according to claim 1, wherein the de-agglomerating of the coated powder is enabled by means of a wet process, using effective means selected from of any suitable mechanical dispersers, mechanical homogenizes, ultra sonic homogenizes or any combination thereof.
30. A metallic powder produced by the method as defined in claim 1 or any of the preceding claims, wherein said powder comprises particles with grain sizes of 1 to 100 nm in at least one direction.
31. The nano-powder according to claim 30, wherein the metal is selected from the group I, IV, V, VI, VII and VIII of the periodic table of elements.
32. The nano-powder according to claim 30, wherein the metal is selected from silver, copper, nickel, cobalt, titanium, palladium, platinum, gold and iridium.
33. The nano-powder according to claim 30, wherein the metal is selected from alloys comprising a blend of silver and at least one other metal, selected from atoms of group I, IV, V, VI, VII and VIII of the periodic table of elements.
34. The nano-powder according to claim 30, comprising about 99.0 % to 99.55 % desired metal, and less then 1% soluble metal, having a specific area of about 6 to 25 m<sup>2</sup> per gram and average particle size of about 50 to 100 nm.